CHAPTER FOUR

The Relative Abundance, Distribution, Composition, and Life History Characteristics of Fishes in Gloucester Harbor

Anthony R. Wilbur
Massachusetts Office of Coastal Zone Management, Boston, MA

Abstract

This study described the fish community structure in Gloucester Harbor and detailed seasonal and spatial characteristics of relative abundance, community composition, and life history traits. Four otter trawl stations and four seine stations were sampled monthly from June 1998 to May 1999. This study was the first effort to assess the Gloucester Harbor fish community in more than 30 years. A total of 1,786 fish (trawl, N = 1,165; seine, N = 621) were collected, comprised of 29 fish species. Skates, winter flounder, and Atlantic cod were the most abundant (by number), totaling 71.5% of the total otter trawl catch. Resident and transient species exhibited seasonal variation in presence and relative abundance with the highest relative abundance (total fish CPUE) in spring and fall. Juvenile fishes dominated catches. The presence of resident species, including commercially exploited species (winter flounder and windowpane) and non-target species (cunner, lumpfish, and rock gunnel), and the seasonal recruitment of marine young-of-year fishes (Atlantic cod, pollock, red hake, and shorthorn sculpin) demonstrated the use of Gloucester Harbor as nursery habitat. Skates dominated the demersal fish biomass. This study demonstrated the importance of nearshore waters, including urban embayments, in Massachusetts to the development of a relatively diverse fish assemblage.

Introduction

Gulf of Maine demersal fishes historically sustained and continue to support productive fisheries in the Northeast United States and the Canadian Maritimes (NMFS 1998). Fishes of the Gulf of Maine are well described (Bigelow and Schroeder 1953; Collette and Klein-MacPhee 2002), and studies describe spatial and temporal features of the demersal fish assemblage found in Northwestern Atlantic offshore waters (Colvocoresses and Musick 1984; Gabriel 1992). Federal and state monitoring programs assess stock status of commercially and recreationally important species throughout the Gulf of Maine and Massachusetts waters (NMFS 1998; Howe et al. 2000a).

Studies examining intraannual variation of fish fauna composition and relative abundance in nearshore Gulf of Maine waters are rare (Lazzari et al. 1999). Massachusetts fishery resources are assessed biannually through stock assessment surveys (Howe et al. 2000a), but nearshore systems (<9m water depth) are not routinely investigated (Howe et al. 2000b). Gloucester Harbor was initially investigated in 1966-1967 to characterize harbor fishery resources (Jerome et al. 1969). The Jerome et al. (1969) study provided valuable information on fishery resources and demonstrated the importance of coastal waters to a relatively diverse fish assemblage.

Recent studies of nearshore systems focused on specific habitats (e.g., Heck et al. 1989) or species (Howe et al. 2000b). Few published studies, however, examine fish distribution, abundance, community characteristics, and habitat use in Gulf of Maine coastal waters (Ayvazian et al. 1992; Lazzari et al. 1999; Chase et al. 2002; Buchsbaum et al. 2003). Coastal, shallow water environments are ecologically important to many marine fish species, especially

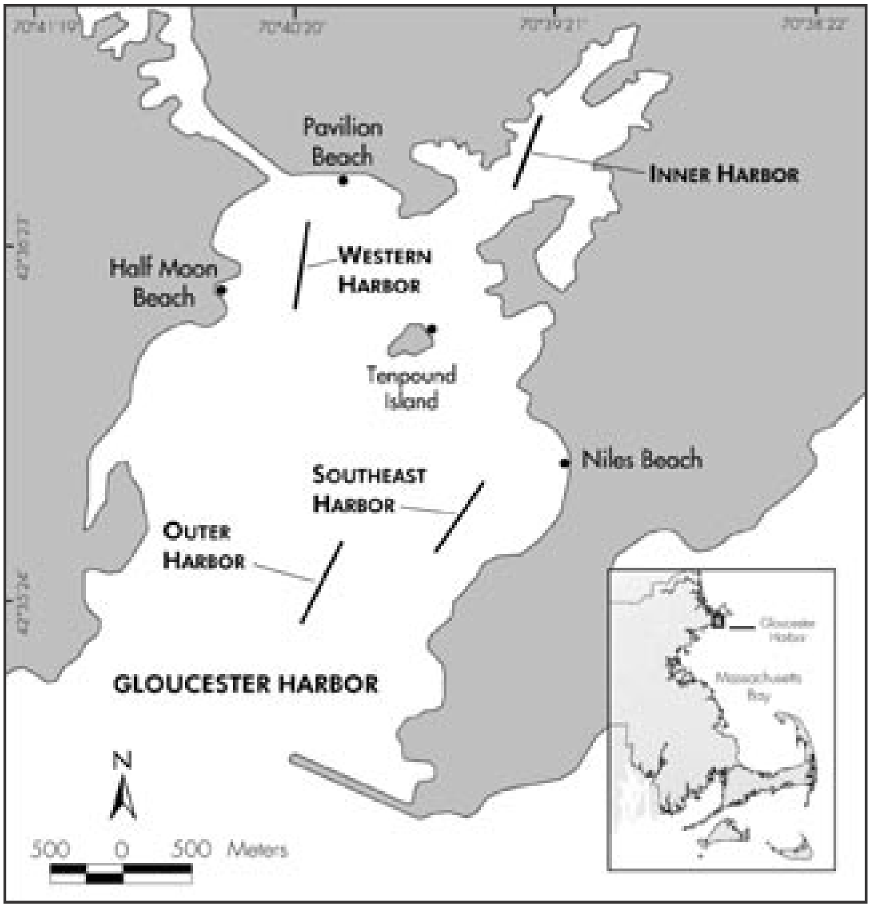

FIGURE 4.1 Study area map. Location of otter trawl and beach seine sampling stations in Gloucester Harbor during June 1998 to May 1999. Lines represent average location of Southeast Harbor (SEH), Outer Harbor (OH), Western Harbor (WH), and Inner Harbor (IH) otter trawl stations. Dots represent beach seine locations.

throughout early ontogenetic development (e.g., Hoss and Thayer 1993; Able and Fahay 1998; Meng and Powell 1999; Howe et al. 2000b). The 1966-1967 study illustrated that juvenile fish inhabit Gloucester Harbor waters (Jerome et al. 1969). Early juvenile fishes require specific habitat conditions that mediate survivorship and growth, and these habitats are often located in nearshore waters. The understanding of early life history requirements of fishes is a critical source of information that is needed to improve the management of coastal waters.

Nearshore marine habitats are diverse and highly susceptible to natural and human perturbations. Embayments were frequently developed to support urban centers, maritime industries, and recreational boating. Harbor development dramatically altered environmental resources and conditions. Anthropogenic influences, including historic and current inputs, affect environmental quality and ecological function of these harbors. Urban embayments present varying degrees of degradation, but contain environmental features that support early life history stages of fishes (Able et al. 1998; Able et al. 1999).

This study documents the results of a twelve-month fish survey in Gloucester Harbor. The objective of the study was to describe fish community structure of Gloucester Harbor and investigate seasonal and spatial characteristics of the fish community, from June 1998 to May 1999. Seasons were defined by examining water temperature and fish assemblage features to facilitate data analyses and description. Total relative abundance (species combined), species

TABLE 4.1 Intertidal seine and subtidal otter trawl sampling stations in Gloucester Harbor, June 1998 to May 1999. Means (SE) included where relevant.

Station	Location[a]		Mean Depth (m)	Substrate	Observations
Seine Sites					
Pavilion Beach	42.6093°N, 70.6680°W			sand	shallow slope
Tenpound Island	42.6023°N, 70.6637°W			sand, gravel, shells	steep slope
Half Moon Beach	42.6045°N, 70.6768°W			sand	moderate slope, ledge on either side
Niles Beach	42.5923°N, 70.6548°W			sand	moderate slope eelgrass offshore
Trawl Sites	*Start*	*End*			
Southeast Harbor	42.6029°N, 70.6675°W	42.5982°N, 70.6730°W	9.9 (0.3)	sand-silt	*Laminaria*, *Agarum*, *Ulva* present
Outer Harbor	42.5985°N, 70.6724°W	42.5929°N, 70.6751°W	11.3 (0.3)	silt-shells	small amounts of macroalgae
Western Harbor	42.6119°N, 70.6744°W	42.6060°N, 70.6758°W	8.0 (0.3)	silt-mud	no macroalgae
Inner Harbor	42.6154°N, 70.6645°W	42.6202°N, 70.6607°W	8.0 (0.2)	soft mud	frequent snags

[a]Average latitude and longitude

composition, and species richness were compared by season and trawl station. Relative abundance and length frequency were documented for common species. Habitat use and the ecological function of harbor waters are discussed for Gloucester Harbor.

MATERIALS AND METHODS

Biological resources were examined in Gloucester Harbor during the development of the Massachusetts Dredged Material Management Plan (MCZM 2001). Fish community characteristics were studied to assess the environmental suitability of in-water dredged material disposal options and evaluate potential impacts.

Study Area

Gloucester Harbor is an urban port in northwestern Massachusetts Bay, Massachusetts (Figure 4.1). The inner harbor supports shoreline and navigation infrastructure, including piers, rip-rap, navigation channels, and mooring areas. The outer harbor shoreline ranges from undeveloped rocky shore and sandy beach to residential property. Seafloor sediments throughout the study area are predominately unconsolidated, soft sediments with areas of ledge and rock (NAI 1999a; Valente et al. 1999; USGS 2000; SAIC 2001; Malkoski personal observation) and patchy distribution of kelp and drift algae (personal observation). Seafloor habitat in the inner harbor is degraded, including chemical contamination and anoxic sediments (Valente et al. 1999; MCZM 2001). Environmental quality improves along a gradient from the inner to outer harbor (Valente et al. 1999; SAIC 2001). Outer harbor sediments generally show negligible evidence of human perturbation (SAIC 2001).

Sampling Techniques

Fishes were sampled in Gloucester Harbor from June 1998 to May 1999. Otter trawl and beach seine sampling was conducted twice per month from June through October 1998 and May 1999 and once per month from November 1998 through April 1999 (18 sample periods; NAI 1999b). Sampling gear and methods used in this project were developed in consultation with Massachusetts Division of Marine Fisheries (DMF). Otter trawl and seine stations were located to represent harbor environs (Table 4.1) and for consistency with previous studies (Jerome et al. 1969; Chase et al. 2002; DMF personal communica-


Beach seine (left), processing a trawl catch (right)

tion). Fixed otter trawl stations were located in the Southeast Harbor (SEH), Outer Harbor (OH), Western Harbor (WH), and Inner Harbor (IH) (72 total trawls). Four seine stations (Pavilion Beach [PB], Tenpound Island [TI], Half Moon Beach [HM], and Niles Beach [NB]) were identified in accessible and haulable waters (i.e., beaches that were capable of being seined) (71 total hauls) (Figure 4.1). Otter trawl and beach seine stations are identified by capital letters throughout the study.

Otter trawl stations were located in waters subjected to a range of human influences. Degradation, including diminished water quality (Kooken et al. 2000) and sediment quality (MCZM 2001), was most prevalent at the IH trawl station. Outer harbor stations (i.e., WH, SEH, and OH) had similar water quality and sediment type, with comparatively less evidence of human influences (SAIC 2001). The PB seine station was a sandy beach adjacent to the inner harbor; TI was located on an island with a mix of sand, gravel, and shells; HM was a sandy beach between a rocky shoreline on the western side of the outer harbor; and NB was located along a sandy beach on the eastern shore (Table 4.1).

A 50-foot seine (15.2 m length; 1.2 m depth; 1.2 x 1.8 m bag; 4.8 mm delta mesh) was used to sample shallow water fishes (intertidal habitat sampling). A 30-foot otter trawl (9.1 m sweep; 8.2 m headrope) sampled fishes in deeper water (subtidal habitat sampling). The otter trawl had 2-inch stretch mesh (5.08 cm) in the body and 1.5-inch stretch mesh (3.81 cm) in the cod end with a 1/4 inch liner (0.64 cm). The cod end liner retained smaller fishes.

The beginning and end coordinates of each trawl sample were recorded, and trawl distance measured with differential Global Positioning System (GPS). The trawl started when trawl doors rested on the seafloor. The trawl ended at 400 m (measured by GPS) and was quickly retrieved to the boat. Tow distance was verified by plotting beginning and end coordinates using Geographic Information System (GIS) software. Otter trawl tow length occasionally varied, so the catch per unit effort (CPUE; number and weight) was standardized to a 400 m tow length (#/400 m). Shallow water habitat (i.e., intertidal) was sampled by positioning the seine parallel to shore in approximately one meter of water and hauled directly to shore, covering a rectangular area. The area sampled (i.e., length of haul and volume of water) for each seine sample was relatively equal, and CPUE was calculated as catch per haul (#/haul).

For each seine and trawl sample, all fishes were identified to species, counted, measured for total length (TL; mm), and weighed (g; aggregate weight by species). Skates (*Leucoraja* spp.) were identified to genus and included little skate (*Leucoraja erinacea*) and winter skate (*Leucoraja ocellata*).

Water Temperature Assessment and Season Identification

Bottom water temperature was recorded with a YSI 600XL water quality meter for each seine and trawl sample (total samples = 128). Instrument failure prohibited water temperature collection on 18 September and 11 November 1998. Trawl and seine stations were separately analyzed to demonstrate difference between shallow and deep waters, and data were described by mean and standard error to show the yearly range of temperature. Trawl water temperature data were compared with the one-way analysis of variance (ANOVA; $p<0.05$) to investigate spatial (station) variability. Season delineation was determined by investigating general trends of bottom water temperature (i.e., increasing, decreasing, or stable) and trawl catches (i.e., variation in CPUE and species assemblage characteristics). These factors provided a rationale for grouping the data by season.

Fish Community and Trawl Station Characterization

Trawl and seine catches were individually analyzed, but the discrete sampling methods collectively provided a description of the harbor fish community. Species composition (% of total CPUE), richness (# of fish species), and total fish relative abundance (species combined, mean CPUE ± standard error; SE) were the parameters used to describe the fish community. Trawl stations and sample periods were combined to describe the overall fish community of the harbor. The temporal characterization of the fish community included analyses by season and month (justification for grouping data by four seasons is presented below). Spatial features were compared by investigating individual trawl stations. Analyses by season and station included relative abundance (mean CPUE ± SE), species richness (mean richness ± SE), and composition (% total CPUE). Relative abundance (total fish monthly mean CPUE ± SE) was analyzed for the seine data to describe temporal characteristics of shallow water fishes. The species list and monthly presence were described by combining otter trawl and beach seine data.

This study examined the hypothesis that temporal and spatial variation in fish assemblage structure existed in Gloucester Harbor. Comparison of seasonal species richness was made with ANOVA, and the Tukey Test examined difference between seasons ($p<0.05$). Parametric assumptions were not always met for variables based on otter trawl samples; therefore, nonparametric methods compared assemblage features. Seasonal CPUE, station CPUE, and station species richness were compared with Kruskal-Wallis Test (non-parametric ANOVA for multiple groups, $p<0.05$). If significant differences were detected with the Kruskal-Wallis statistic, the Mann-Whitney Rank Sum Test (non-parametric statistical equivalent to T-Test for two groups) was used to evaluate two samples (e.g., spring and winter CPUE). The Bonferroni correction adjusted the Mann-Whitney statistic significance value ($p<0.0125$) to reduce the potential of type I error (i.e., rejection of true null hypothesis) for each comparison (Sokal and Rohlf 1995).

Relative Abundance and Length Frequency

Seasonal variation in relative abundance and length-frequency distributions was examined for common species. Relative abundance analysis focused on the top nine species (by number). Length-frequency distributions were described for Atlantic cod (*Gadus morhua*), winter flounder (*Pseudopleuronectes americanus*), and skates (*Leucoraja* spp.).

RESULTS

Season Delineation

Four seasons were identified by comparing water temperature and fish data. Water temperature fluctuation generally corresponded to total relative abundance (Figure 4.2). Seasonal characteristics are summarized in Table 4.2. Spring (April-June; 5 sample periods) was characterized by increasing water temperature and relatively high abundance and richness of fishes; summer (July-September; 6 sample periods) had warm water and relatively stable abundance and moderate richness of fishes; fall (October-December; 4 sample periods) illustrated dramatic water temperature decline, a slight increase and subsequent decrease in relative abundance, and comparatively high species richness; winter (January-March; 3 sample periods) was characterized by stable low water temperatures and low abundance and richness of fishes.

This study used assemblage composition and species richness to assist in determining seasons (Table 4.2; detailed examination of fish data provided below). Characteristics, such as the presence of juvenile Atlantic cod and shorthorn sculpin, overlapped between late winter (March) and early spring (April). The substantially larger catches (total CPUE by number) of Atlantic cod and shorthorn sculpin, occurrence of juvenile pollock, and higher species richness (total number of fish species) in April was used as an ecological indicator of the winter-spring transition. These defined seasons were used for additional analyses of the fish community throughout the study.

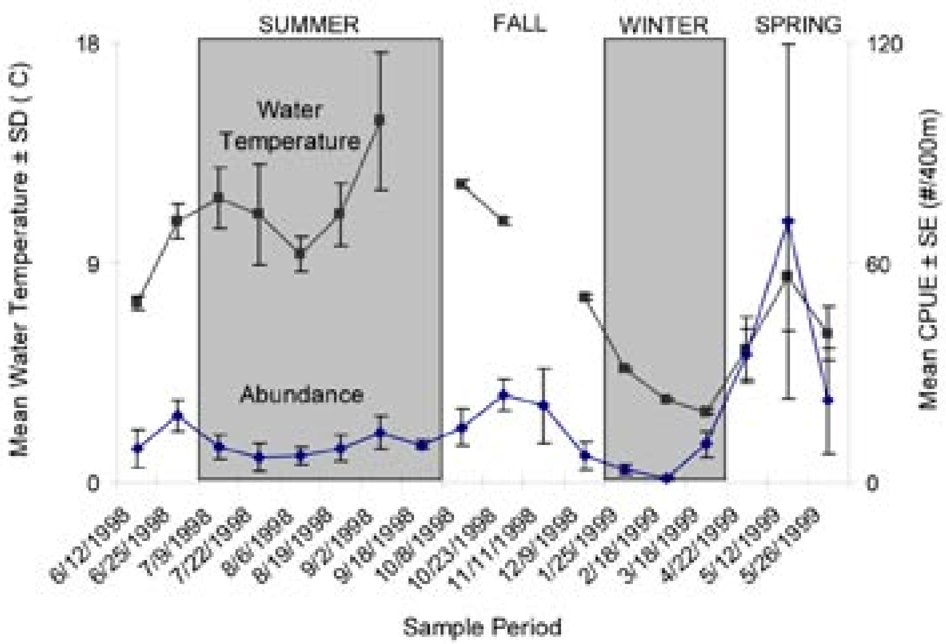

FIGURE 4.2 Seasonal illustration of sample period mean and variation in bottom water temperature and relative abundance of fishes (water temperature and total CPUE for otter trawl data). Water temperature not collected on 18 September and 11 November 1998.

TABLE 4.2 Seasonal water temperature, relative abundance of fishes (total fish catch of combined otter trawl stations) and species richness (total number of fish species per sample period). Mean (SE) included where relevant.

Season	Months[a]	Water Temperature (°C)	CPUE	Species Richness
Spring	April-June (5)	7.6 (0.5)	31.0 (10.4)	11.0 (1.6)
Summer	July-September (6)	11.5 (0.6)	9.4 (1.3)	7.3 (0.8)
Fall	October-December (4)	10.2 (0.6)	16.6 (3.3)	10.5 (1.0)
Winter	January-March (3)	3.6 (0.2)	4.8 (1.6)	3.3 (1.3)

[a]Number of sample periods are given in parentheses.

Water Temperature

Water temperature (mean water temperature ± SE) at trawl stations ranged from 2.9 ± 0.1°C (18 March 1999) to 14.8 ± 2.8°C (2 September 1998). Temperature from the seine stations ranged from 3.3 ± 0.1°C (18 February 1999) to 19.0 ± 0.7°C (22 July 1998). Water temperature at seine stations was higher compared to the trawl stations during June and July 1998 and May 1999 and comparable among seine and trawl stations from end of August 1998 to March 1999 (Figure 4.3).

Bottom water temperatures at trawl stations were not significantly different (ANOVA, $p>0.05$; Table 4.3). IH (9.2 ± 1.0°C) and OH (7.8 ± 0.7°C) had the highest and lowest mean temperature, respectively. Variability observed in bottom water temperature suggested that IH water temperature was notably higher than outer harbor stations (SEH, WH, and OH) during July, August, and September.

Fish Community Characteristics

Twenty-nine fish species were collected in Gloucester Harbor, including the trawl (22 fishes) and seine (20 fishes; Table 4.4). A total of 1,786 fish (trawl, N = 1,165; seine, N = 621) were collected during the study (Appendix 4.1-4.4d). Community characteristics differed between trawl and seine samples.

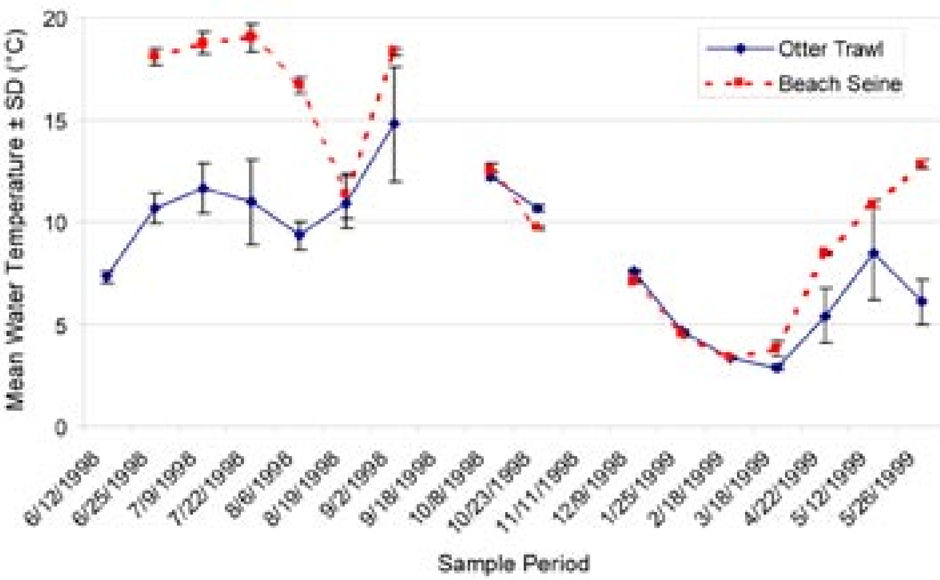

FIGURE 4.3 Bottom water temperature (mean ± SD) at seine and trawl stations for each sample period, June 1998 to May 1999. Water temperature not collected on 18 September and 11 November 1998.

TABLE 4.3 Seasonal mean bottom water temperatures (SE) at otter trawl stations. Total represents study mean.

Station	Spring	Summer	Fall	Winter	Total
Southeast Harbor	7.4 (1.3)	11.0 (0.6)	10.1 (1.4)	3.6 (0.5)	8.3 (0.8)
Outer Harbor	6.6 (0.9)	10.2 (0.7)	10.3 (1.4)	3.6 (0.5)	7.8 (0.7)
Western Harbor	7.8 (1.1)	12.0 (1.2)	10.1 (1.3)	3.7 (0.5)	8.8 (0.9)
Inner Harbor	8.4 (0.7)	12.9 (1.5)	10.1 (1.4)	3.6 (0.6)	9.2 (1.0)

Trawl collections were comprised of skates (24.9%), winter flounder (24.1%), Atlantic cod (22.5%), and other demersal fishes (e.g., rock gunnel [3.4%], shorthorn sculpin [3.3%], red hake [3.1%], and pollock [3.1%]) (Figure 4.4). Skates dominated overall harbor biomass (80.0% of total biomass). Fish composition varied between the seasons (Figure 4.5). Juvenile recruitment of Atlantic cod (35.2%) and pollock (5.8%) to nearshore waters was observed in spring. Spring samples contained 19 total species, including skates (19.9%), winter flounder (19.8%), and shorthorn sculpin (5.0%). Skates (45.6%) and winter flounder (24.3%) constituted the majority of the summer composition (15 total species). Fifteen species were collected during fall. These samples were dominated by winter flounder and skates (32.2% and 24.0%, respectively), with Atlantic cod (8.6%), cunner (5.6%), red hake (5.2%), and lumpfish (4.6%) constituting a substantial portion. The winter fish assemblage (7 species) was comprised of winter flounder (31.6%), Atlantic cod (31.6%), rock gunnel (15.8%), shorthorn sculpin (8.8%), cunner (5.3%), and grubby (5.3%).

The number of fishes (species richness) varied through the study (Figure 4.6). The greatest fish species richness was observed during late summer, early fall, and spring. Fifteen species were found in October 1998, and April and May 1999. The lowest richness was during the winter (January [2 species]-March [6 species]). Species richness differed by season (Table 4.2; ANOVA, $p<0.05$), with spring (mean total # of species per sample period ± SE; 11.0 ± 1.6; Tukey, $p<0.05$) and fall (10.5 ± 1.0; Tukey, $p<0.05$) greater than winter (3.3 ± 1.3).

TABLE 4.4 Common and scientific names of fishes encountered in the June 1998 to May 1999 otter trawl and beach seine survey, seasonal presence[a] and method of collection.

Common Name	Scientific Name	Seasonal Presence[a]	Collection Method
American sand lance	*Ammodytes americanus*	October (1)	seine
Atlantic cod	*Gadus morhua*	June; August; October-November March-May (7)	trawl
Atlantic menhaden	*Brevoortia tyrannus*	September-October (2)	seine
Atlantic silverside	*Menidia menidia*	August-December; February-May (9)	seine & trawl
Bay anchovy	*Anchoa mitchilli*	July-August (2)	seine
Blueback herring	*Alosa aestivalis*	June-August (3)	seine & trawl
Bluefish	*Pomatomus saltatrix*	September (1)	seine
Butterfish	*Peprilus triacanthus*	September (1)	trawl
Cunner	*Tautogolabrus adspersus*	June-July; September-November; February-May (9)	seine & trawl
Grubby	*Myoxocephalus aenaeus*	June-October; December-January; April (8)	seine & trawl
Longhorn sculpin	*Myoxocephalus octodecemspinosus*	September-December; May (5)	trawl
Lumpfish	*Cyclopterus lumpus*	June; August-December (6)	seine & trawl
Mummichog	*Fundulus heteroclitus*	August; October-November (3)	seine
Northern pipefish	*Syngnathus fuscus*	June-July; September-November; April (6)	seine & trawl
Northern puffer	*Sphoeroides maculatus*	September (1)	seine
Ocean pout	*Macrozoarces americanus*	April-May (2)	trawl
Pollock	*Pollachius virens*	April-May (2)	seine & trawl
Radiated shanny	*Ulvaria subbifurcata*	June; April (2)	trawl
Rainbow smelt	*Osmerus mordax*	July; September-December; April (6)	seine & trawl
Red hake	*Urophycis chuss*	June-November; April-May (8)	seine & trawl
Rock gunnel	*Pholis gunnellus*	June-July; September-December; February-May (10)	seine & trawl
Sea raven	*Hemitripterus americanus*	June; October; May (3)	trawl
Seasnail spp.	*Liparis spp.*	August; April-May (3)	trawl
Shorthorn sculpin	*Myoxocephalus scorpius*	June; October-November; March-May (6)	seine & trawl
Skates[b]	*Leucoraja spp.*	June-December; April-May (9)	trawl
Threespine stickleback	*Gasterosteus aculeatus*	June; May (2)	seine
White hake	*Urophycis tenuis*	June; April (2)	trawl
Windowpane	*Scophthalmus aquosus*	June-December; March; May (9)	seine & trawl
Winter flounder	*Pseudopleuronectes americanus*	June-January; March-May (11)	seine & trawl

[a]Total number of months present are given in parenthesis.

[b]Skates are mix of little skate *(Leucoraja erinacea*) and winter skate *(Leucoraja ocellata*)

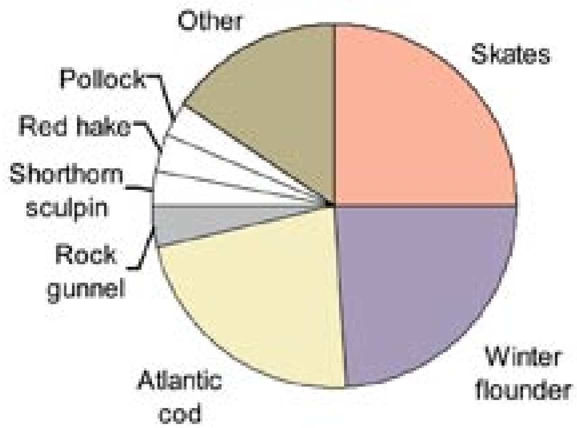

FIGURE 4.4 Fish composition (%) of otter trawl stations (otter trawl stations combined; total CPUE by number) in Gloucester Harbor, June 1998 to May 1999.

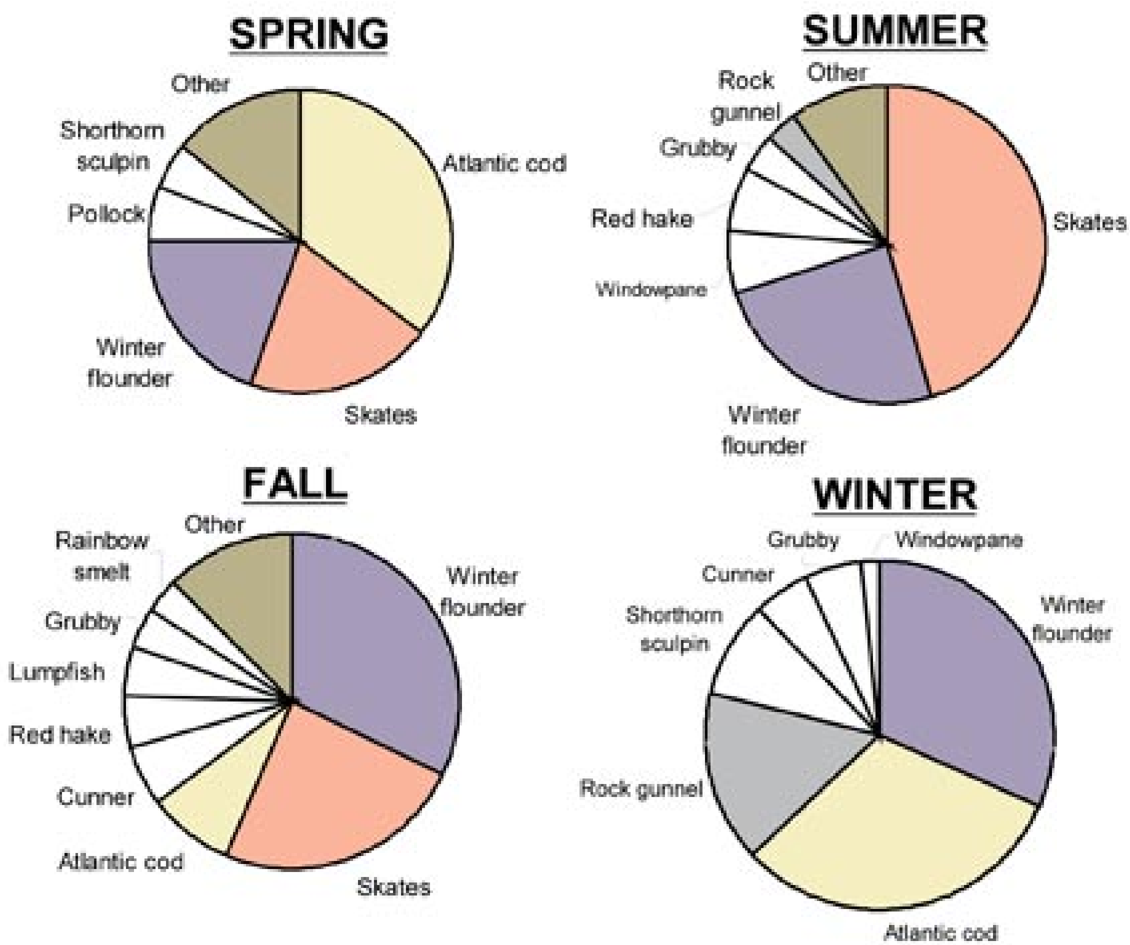

FIGURE 4.5 Seasonal percent composition (%) of fishes (otter trawl stations combined; CPUE by number).

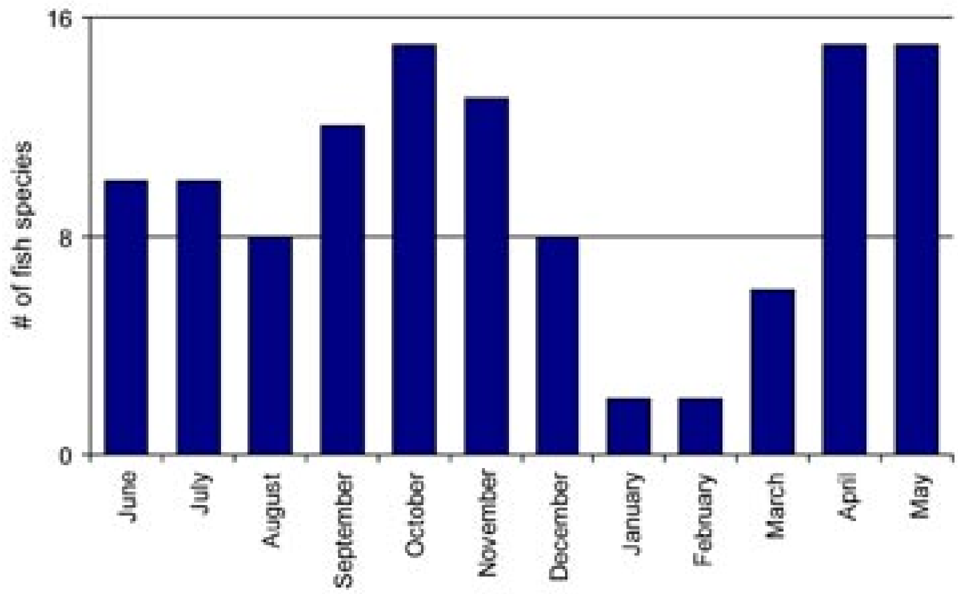

FIGURE 4.6 Monthly total fish species richness (# of species) in Gloucester Harbor from June 1998 to May 1999 (trawl stations combined).

There was significant seasonal variability in the total relative abundance of fishes (Kruskal-Wallis, $p<0.001$). Spring collections (mean CPUE ± SE; 31.0 ± 10.4 CPUE) were greater than summer (9.4 ± 1.3 CPUE; Mann-Whitney, $p<0.0125$) and winter (4.8 ± 1.6 CPUE; Mann-Whitney, $p<0.001$) but not different than fall (16.6 ± 3.3 CPUE; Mann-Whitney, $p=0.3$). The greatest variance (based on SE) of CPUE was observed during spring. Summer catches did not differ from winter (Mann-Whitney, $p=0.02$), but fall CPUE was greater than winter (Mann-Whitney, $p<0.0125$).

There were notable monthly fluctuations in relative abundance, and seasonal relative abundance was often influenced by large catches within a particular month (Appendix 4.1-4.2d). April (34.8 ± 6.8 CPUE) and May (46.5 ± 25.1 CPUE) presented the highest monthly catches, contributing to the spring relative abundance. Winter had low relative abundance with the lowest catches in January (3.2 ± 1.4 CPUE) and February (0.8 ± 1.4 CPUE). Fall abundance was influenced by October (19.3 ± 3.5 CPUE) and November (20.8 ± 10.2 CPUE) samples.

The seine collections were dominated by relatively large catches of Atlantic silverside in September (total catch by number = 162) and early October (301). Atlantic silverside contributed 77% of total seine catch by number. A relatively large catch of lumpfish occurred in early September (37 fish at HM). The lumpfish were associated with beach wrack (personal observation). Seine catches (# of fish/haul) were consistently low throughout the study (Appendix 4.3-4.4d). Low catches ranged from 1.3 to 3.4 fish per haul (June-August 1998) and 0 to 1 fish per haul (November 1998-May 1999), and catches peaked in September (26.8 ± 12.7 fish/haul) and October (41.2 ± 35.7 fish/haul). American sand lance, Atlantic menhaden, bay anchovy, bluefish, mummichog, northern puffer, and threespine stickleback were species collected by the seine and not trawl sampling (Table 4.4).

Temporal frequency (# of months present) was determined using trawl and seine data (Table 4.4). Atlantic silverside, cunner, grubby, rock gunnel, skates, windowpane, and winter flounder were collected at a minimum of one station during 75% (or greater) of the months. Atlantic cod, lumpfish, northern pipefish, rainbow smelt, red hake, and shorthorn sculpin were found during 50% (or greater) of the months. Other demersal fishes (e.g., longhorn sculpin, sea raven, and ocean pout) and several schooling (e.g., Atlantic menhaden) and anadromous fishes, such as rainbow smelt and blueback herring, were infrequently collected but were important seasonal components of the fish assemblage.

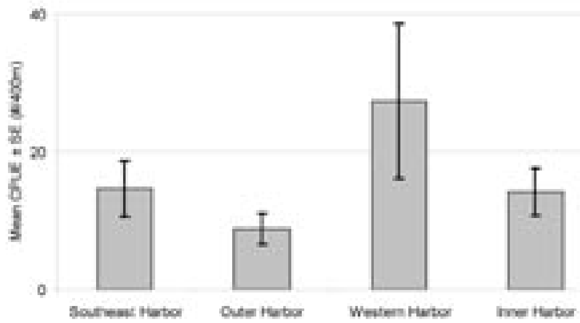

FIGURE 4.7 Otter trawl station total (species combined) annual CPUE (SE) mean (#/400m).

Station Community Assessment

Relative abundance, species richness, and composition were variable between otter trawl stations. The greatest total mean CPUE was found at WH (27.3 ± 11.2 CPUE), but was not significantly higher than SEH (14.7 ± 4.1 CPUE), IH (14.1 ± 3.4 CPUE), and OH (8.8 ± 2.2 CPUE) (Kruskal-Wallis; p=0.05) (Figure 4.7). Station total mean CPUE was frequently affected by relatively large individual catches (Appendix 4.2a-4.2d). The WH mean was particularly influenced by a large catch of young-of-year (YOY) Atlantic cod (151.0 CPUE) on 12 May 1999.

Seasonal characteristics of relative abundance varied among trawl stations (Figure 4.8; Appendix 4.2a-4.2d). Seasonal relative abundance was greatest in spring at SEH (31.9 ± 11.7 CPUE) and WH (60.5 ± 38.7 CPUE). Large catches of YOY Atlantic cod affected the spring CPUE at WH and SEH. OH (16.2 ± 6.9 CPUE) and IH (23.7 ± 10.2 CPUE) illustrated highest relative abundance during the fall. The IH collections in the fall were predominantly comprised of winter flounder (48.0% of fall CPUE). Summer and winter collections did not substantially vary among stations.

Species richness (total # of species per sample period) did not differ among otter trawl stations (Kruskal-Wallis; p>0.05). Species richness (mean richness ± SE) was 4.9 ± 0.6 species at WH, 4.1 ± 0.6 species at SEH, 4.1 ± 0.7 species at IH, and 3.4 ± 0.5 species at OH.

Skates, winter flounder, and Atlantic cod were dominant components of catch composition at each trawl station but composition varied (Figure 4.9). SEH

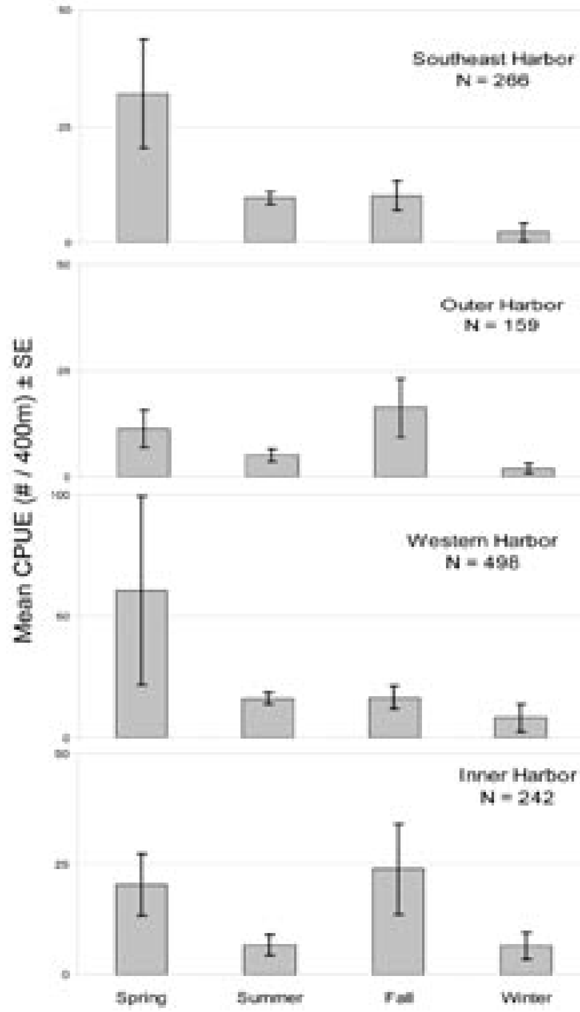

FIGURE 4.8 Seasonal abundance of fishes (CPUE mean ± SE) at otter trawl stations. N=total number of fishes collected. Note different scale at Western Harbor.

total catch was comprised of winter flounder (22.5%), skate species (21.4%), and less common species, including Atlantic cod (15.2%), rock gunnel (9.8%), and pollock (9.5%). Winter flounder accounted for 35.7% of the OH total catch with notable catches of Atlantic cod (19.5%), skate species (10.1%), cunner (8.2%), and longhorn sculpin (3.2%). WH community consisted of Atlantic cod (35.2%), skates (32.4%), and winter flounder (16.4%). Winter flounder (33.4%) and skates (23.1%) dominated IH composition, and Atlantic cod (7.3%), grubby (5.4%), shorthorn sculpin (4.4%), windowpane (4.1%), and rainbow smelt (4.1%) contributed smaller portions to the catch.

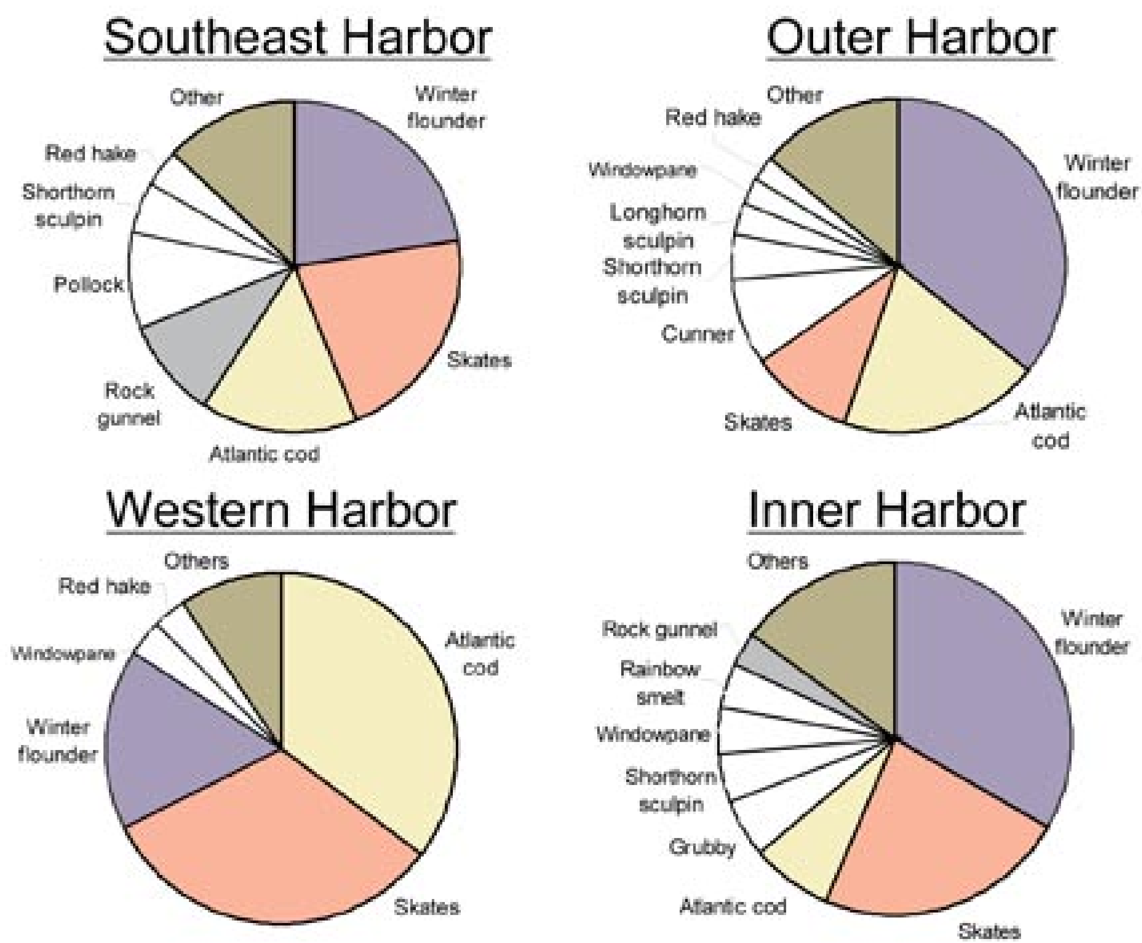

FIGURE 4.9 Trawl station fish composition (% of total CPUE; by number) in Gloucester Harbor, June 1998 to May 1999.

Seasonal Abundance of Common Species

Seasonal occurrence and relative abundance of common fishes was illustrated by total CPUE per sample period (Figure 4.10). Skates were abundant in the spring, summer, and fall, and were absent in the winter. Winter flounder were abundant throughout the year, peaking in October-November 1998 and April and early-May 1999. Windowpane presented two peaks in abundance (9 July 1998 and 12 May 1999). Pollock were collected in spring 1999 (April and May). Atlantic cod were found in summer (25 June and 19 August) and fall (October and November) of 1998 and at a substantially higher relative abundance from March-May 1999. Rock gunnel were encountered during most of the study, with two peak periods of abundance from September-November 1998 and March-May 1999. Shorthorn sculpin were relatively abundant during spring 1999 (March-May 1999). Red hake were present throughout the study, except during the winter (January-March 1999), peaking in June-July and October-November 1998. Cunner were abundant during October-November 1999 and 12 May 1999.

Atlantic Cod, Winter Flounder, and Skate Species Length Distribution

Atlantic cod collected were YOY, ranging from 24 mm TL to 125 mm TL (Figure 4.11). The 1998 YOY cod were collected in June, August, October, and November 1998. The 1999 year class recruited to the harbor in March 1999 and remained through May 1999. Analysis of length illustrated that cod recruited to the harbor around the period of settlement (~25-50 mm TL; Fahay et al. 1999), and modal progression of length provided evidence of growth (Figure 4.12). Cod size distribution and mean size

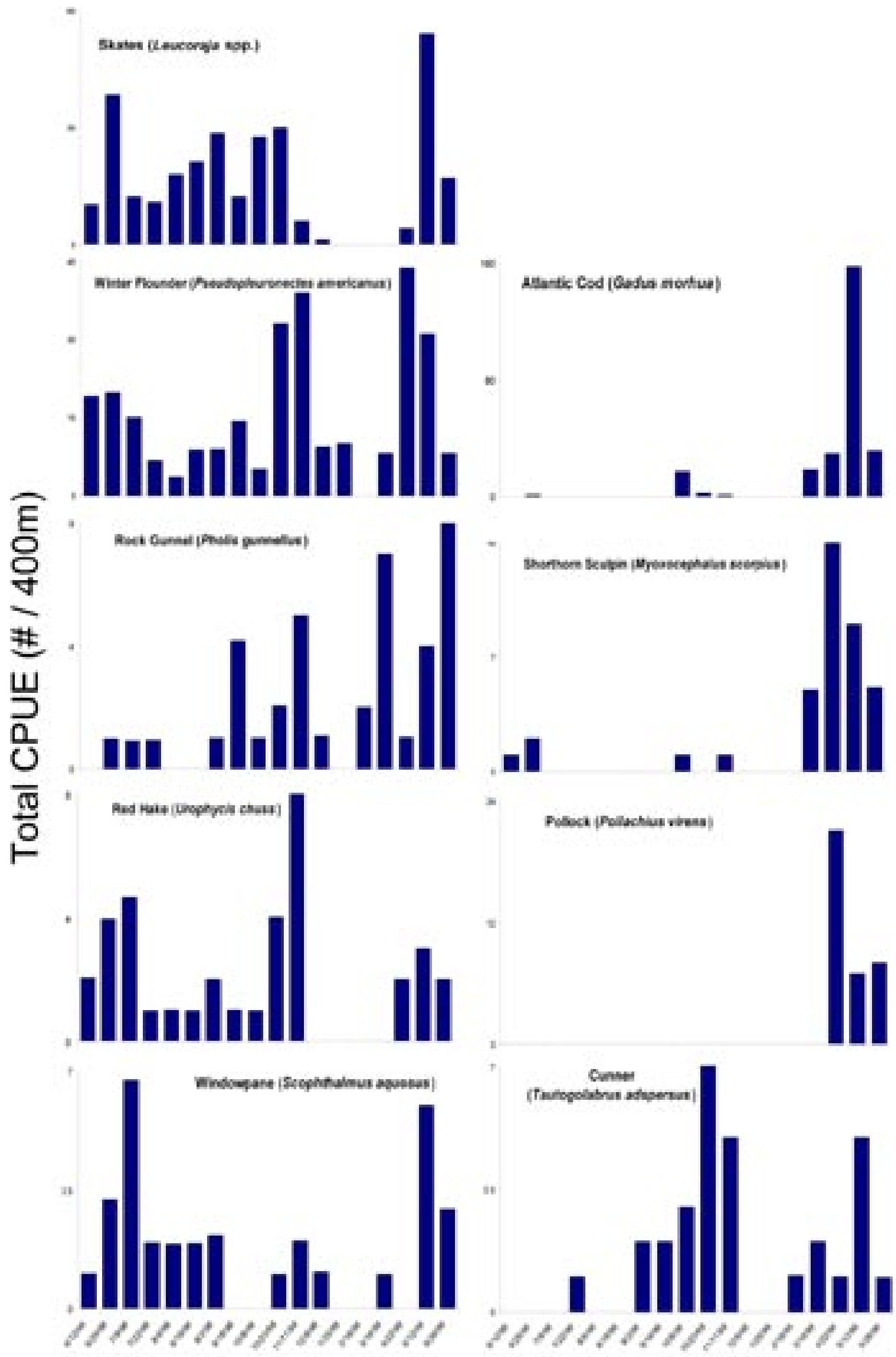

FIGURE 4.10 Total catch per unit effort (sum CPUE - #/400m) for Gloucester Harbor otter trawl stations combined of common fish species, June 1998 to May 1999. Note different scales.

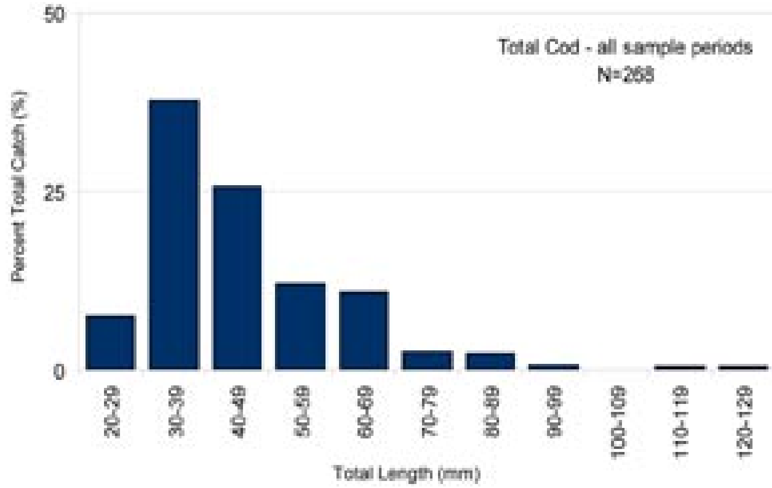

FIGURE 4.11 Composite length frequency of total collection of Atlantic cod (*Gadus morhua*) in Gloucester Harbor. N=total number of cod.

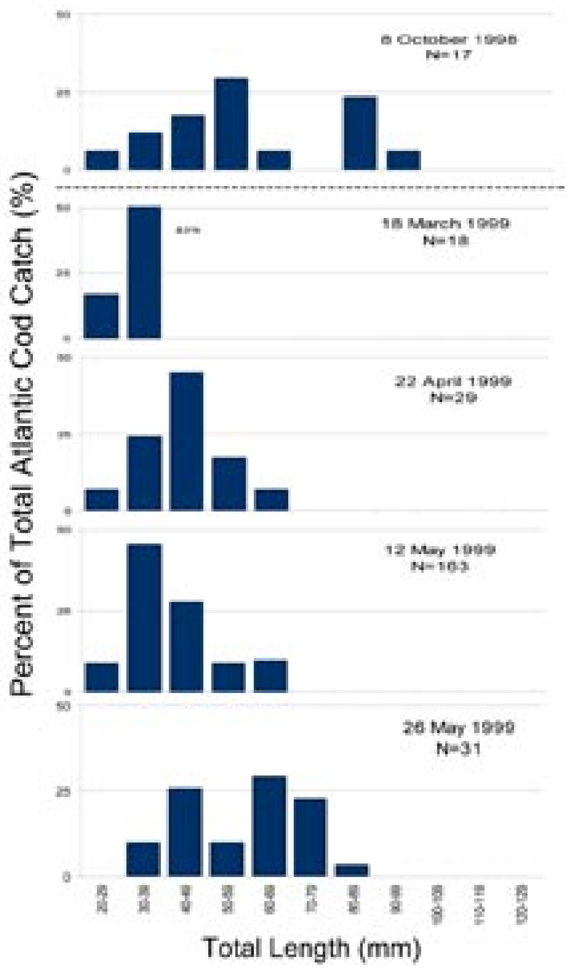

FIGURE 4.12 Sample period length frequency of Atlantic cod, 8 October 1998 and 18 March to 26 May 1999. N=number of cod collected. Cod were collected at low numbers (<5) in June, August, 23 October, and November 1998 (data not shown).

TABLE 4.5 Date and mean (SE) total length (TL) of Atlantic cod collected in Gloucester Harbor in 8 October 1998 and March to May 1999. Length data not shown for small catches in June, August, 23 October, and November 1998.

	Total Length		
Date	Mean	Minimum	Maximum
8-Oct	59.1 (5.2)	25	90
18-Mar	32.5 (0.7)	24	36
22-Apr	42.8 (1.8)	24	66
12-May	40.7 (0.8)	24	67
26-May	57.6 (2.6)	36	80

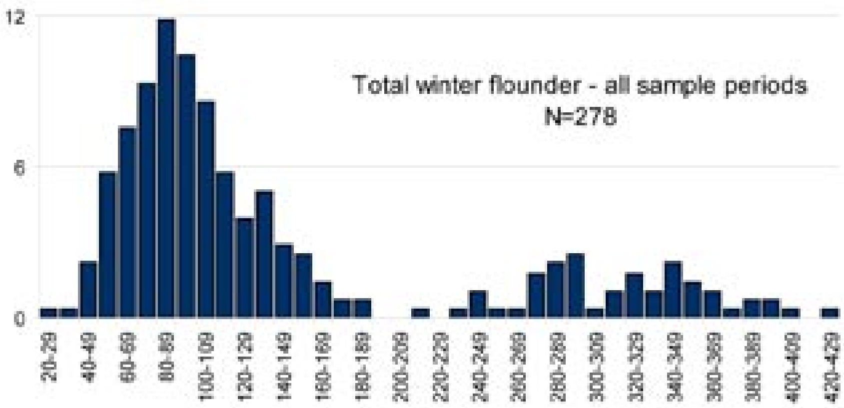

FIGURE 4.13 Composite length frequency of total winter flounder (*Pseudopleuronectes americanus*) in Gloucester Harbor; trawl samples. N=total number of winter flounder collected during the study.

increased from March to May 1999 (Table 4.5). Mean length observed in October 1998 and 26 May 1999 were similar.

YOY, age 1 (yearling), and older winter flounder were found in the harbor, and there was considerable overlap in age class (Howe personal communication; Able and Fahay 1998) (Figure 4.13). YOY and age 1 fish (25 mm to ~ 160 mm TL) were present throughout the study. Multiple year classes, including age two fish and older (220 mm to 425 mm TL; age 2 to 5), age 1 fish (1997 year class; 60 mm to ~140 mm TL), and YOY (1998 year class; < 50 mm TL) were collected from June 1998 to October 1998 and May 1999 (Appendix 4.5). YOY winter flounder were first collected in August 1998 (25 mm to 50 mm TL) and apparently remained in the harbor. During June to November 1998, yearlings (1997 year class; 60 mm to ~180 mm TL) were mostly collected. Relatively low abundance was seen in December 1998-March 1999. Winter flounder collected during this period appeared to be a mix of YOY and age 1 fish (43 mm to 129 mm TL; average length = 79.1 mm TL). Catches increased during April to May 1999 and were mainly 1998 YOY. Larger individuals were also collected in May 1999.

Skate length ranged from 115 mm TL to 595 mm TL (mean TL ± SE = 437.9 ± 5.1). Chase et al. (2002) identified a subset of skates (*Leucoraja* spp.) collected in Salem Sound to species and indicated the majority of skates were little skate (*Leucoraja erinacea*). Based on the Chase et al. (2002) study, similarity in embayments with respect to geographic location and

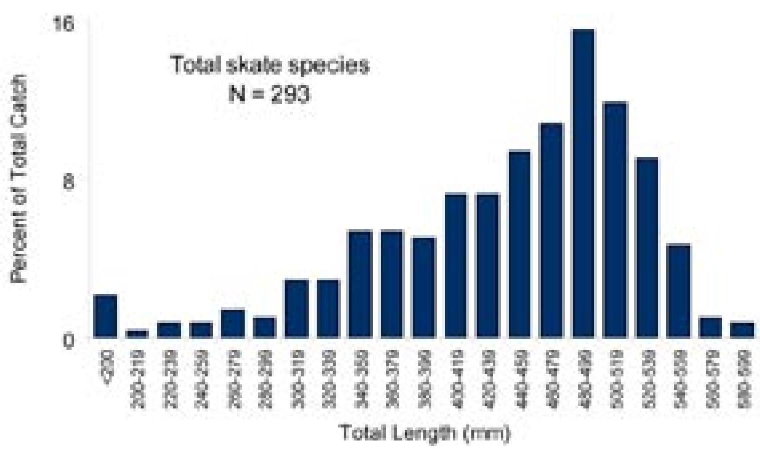

FIGURE 4.14 Composite length frequency of total skates (*Leucoraja* spp.) collected in Gloucester Harbor. N=total number of skates collected during the study.

TABLE 4.6 Fishes collected at Southeast Harbor and Outer Harbor trawl stations during 1966 - 1967[a] (Jerome et al. 1969) and 1998 - 1999 surveys.

Common Name	Scientific Name	1966-1967[a]	1998-1999
Atlantic cod	*Gadus morhua*	X	X
Atlantic tomcod	*Microgadus tomcod*	X	
Blueback herring	*Alosa aestivalis*		X
Cunner	*Tautogolabrus adspersus*	X	X
Grubby	*Myoxocephalus aenaeus*		X
Longhorn sculpin	*Myoxocephalus octodecemspinosus*		X
Lumpfish	*Cyclopterus lumpus*	X	X
Northern pipefish	*Syngnathus fuscus*		X
Ocean pout	*Macrozoarces americanus*		X
Pollock	*Pollachius virens*	X	X
Rainbow smelt	*Osmerus mordax*	X	X
Red hake	*Urophycis chuss*		X
Rock gunnel	*Pholis gunnelus*		X
Sea raven	*Hemitripterus americanus*	X	X
Seasnail	*Liparis spp.*	X	X
Shorthorn sculpin	*Myoxocephalus scorpius*		X
Skates	*Leucoraja spp.*		X
White hake	*Urophycis tenuis*		X
Windowpane	*Scophthalmus aquosus*		X
Winter flounder	*Pseudopleuronectes americanus*	X	X
Yellowtail flounder	*Limanda ferruginea*	X	
	Total Species =	10	19

[a]Stations identified as Niles Beach and Southeast Harbor in 1966 - 1967 were approximately located at the 1998 - 1999 Southeast Harbor and Outer Harbor stations, respectively.

habitat, and life history reviews (Packer et al. 2000a; Packer et al. 2000b), skates collected during this survey were presumably little skate. Little skate life history information was used for the skate length results and discussion.

The majority of skates collected were juvenile (sexually immature; < 500 mm TL) (Figure 4.14). Skates were largely found in the range of 340 mm TL to 540 mm TL with a few smaller (YOY and 1 year skates < 200 mm TL) and larger (> 540 mm TL; age 5 and older). Skates were substantially larger, demonstrated by length and biomass, than other fishes collected during the survey.

Discussion

This study described the fish community in Gloucester Harbor during 1998-1999, and was the first assessment of fishes since 1966-1967 (Jerome et al. 1969). Environmental conditions and quality, fish populations and human influences changed during the past 30 years. This study cannot directly evaluate the effect of these changes on coastal fishes, and comparison of the 1998-1999 and 1966-1967 studies are qualitative (Table 4.6). The 1998-1999 study updated findings from 1966-1967 (Jerome et al. 1969) and provided baseline data for future studies and monitoring.

Water Temperature & Seasonal Classification

Large-scale oceanographic attributes, including water temperature, salinity, and depth, influence the relative abundance, distribution, and composition of fishes (e.g., Oviatt and Nixon 1973; Colvocoresses and Musick 1984; Gabriel 1992). These attributes and processes seasonally fluctuate and demonstrate interannual and intraannual variation. Resource management strategies, such as seasonal restrictions applied to coastal alteration projects, and monitoring programs (e.g., environmental assessment) frequently attempt to predict the variation in environmental attributes to achieve and optimize program objectives. Data used to inform management and monitoring decisions are often aged or absent and require validation. This study investigated approaches to identify ecologically appropriate and distinct seasons based on the combination of biotic and water temperature characteristics in Gloucester Harbor to characterize and explain—in part—the temporal variation of fish assemblages from June 1998 to May 1999.

Water temperature showed a typical seasonal cycle with peak temperature in late summer to lowest temperature in winter. Higher spring and summer water temperatures at beach seine sites compared to deep water trawl stations were predictable given the capacity of shallow water to warming. Water temperature did not differ between trawl stations, but data suggested episodic occurrence of warmer temperature at IH and WH during summer and early fall. Reduced tidal flushing in the inner harbor, occurring from meteorological events (e.g., southwest winds) and the semi-enclosed geography and manmade structures that limit tidal exchange, can affect water temperature. WH temperature was potentially influenced by daily tidal activities and water flow from the Annisquam River. Outer harbor water temperature, including SEH and OH stations, may be dominated by tidal flushing with waters outside of Gloucester Harbor (i.e., Massachusetts Bay).

Water temperature generally affected fish community structure, and periods of the warmest (summer) and coolest (winter) water temperature presented relatively stable water temperature and fish assemblage characteristics (Figure 4.2). Fall and spring were more complex, showing prominent temperature and fish assemblage change. The winter-spring transition was clouded because of similar features (water temperature and fish assemblage) observed in March and April, but fish community attributes, including the presence and relative abundance of juvenile fishes (i.e., Atlantic cod, pollock, and shorthorn sculpin) and species richness, facilitated the spring designation. This transition may be an ecologically important period. The seasons were effectively used to group data, investigate temporal variation, and describe fish community structure, and they corresponded to other Gulf of Maine studies (Ayvazian et al. 1992; Lazzari et al. 1999). Multiple-year surveys are needed to rigorously assess temporal trends, including interannual and intraannual variation; therefore, season identification and discussion were limited in this study by the lack of interannual comparisons.

Understanding long- and short-term seasonal variability is tantamount to effective resource management and monitoring. For example, this study showed the change in the relative abundance and size of juvenile cod species through one year, suggesting that nearshore Gulf of Maine waters are especially important for juvenile cods in late winter to early spring. Increased frequency of fish sampling from early March to June may further characterize the importance of nearshore environments to the survivorship and growth of Atlantic cod and pollock. Targeted experiments and long-term monitoring may improve the understanding of seasonal fluctuation of biotic and abiotic qualities, and provide data to support, justify and improve seasonal management strategies (i.e., environmental windows).

Fish Community

The composition of fishes in Gloucester Harbor consisted of a high proportion of resident species and seasonal peaks in relative abundance of transient species, which is characteristic of boreal fish community structure (Ayvazian et al. 1992). Resident species were found at varying relative abundance throughout the study. Transients included marine and anadromous fishes and largely contributed to the total catch. Catches were principally comprised of demersal juvenile fishes that are effectively collected with the otter trawl used in this study (i.e., small otter trawls potentially underestimate larger, older individuals and pelagic species that avoid the sample gear). Skates, winter flounder, and Atlantic cod were dominant taxa in each season. These species were also the three most abundant species in a recent Salem Sound study (Chase et al. 2002). Relative abundance (CPUE) and species richness were highest in the spring and fall. This observation differs from Salem Sound findings of the highest relative abundance and richness in warmer summer and fall months (Chase et al. 2002). The variability between Salem Sound and Gloucester was probably the result of interannual variation or unidentified differences in habitat condition.

Jerome et al. (1969) studied fishes of the Annisquam River and Gloucester Harbor, and sampling stations included salt marsh and harbor habitats. The current study exclusively focused on harbor waters. The SEH and OH trawl stations were sampled during both studies (or were approximately located in similar areas of the harbor). These stations allowed qualitative comparison between fish community attributes described in 1966-1967 and 1998-1999 (Table 4.6; Jerome et al. 1969).

Total species richness and species presence showed notable differences between the two studies, with more fish species collected in 1998-1999 (19 species) than in 1966-1967 (10 species). Winter flounder and Atlantic cod represented major parts of the catch during the 1966-1967 and 1998-1999. Skates were not collected at the analogous trawl stations during 1966-1967, but skates were a dominant component (i.e., relative abundance and biomass) in 1998-1999. Skates were a minor contributor to collections at a 1966-1967 trawl station located south of the harbor (outside Dog Bar Breakwater). No yellowtail flounder were collected in 1998-1999 and were the third most abundant (by number) species in 1966-1967. Commercially exploited species, including ocean pout, red hake, white hake, and windowpane, and species not targeted for harvest (i.e., grubby, longhorn sculpin, northern pipefish, rock gunnel, and shorthorn sculpin) were present in 1998-1999 but not 1966-1967 (Table 4.6).

Species richness and presence observed in this study and recent Massachusetts Bay surveys (Chase et al. 2002; Buchsbaum et al. 2003) differed from historic studies (e.g., Jerome et al. 1969), which suggests a shift in the demersal fish community structure from the 1960s to the late 1990s. Changes have been reported in other New England estuaries (i.e., diminished flounder distribution and abundance and an increased proportion of pelagic species in the fish community; Jeffries and Terceiro 1985; Meng and Powell 1999; Hughes et al. 2002b; Wyda et al. 2002), and oceanic systems (i.e., replacement of cod and flounder species by dogfish sharks and skates; Fogarty and Murawski 1998). Differences between recent and historic studies may be due to different survey methodology, natural population fluctuation, or anthropogenic perturbation (e.g., commercial exploitation, indirect effects of fishing and habitat degradation), but repeated results provide strong indication of a change in the fish community. The cause for faunal change is not known. Large-scale environmental variation, such as water temperature, will influence catches (Jeffries and Terceiro 1985) and the seasonal distribution and presence of species. Discussion of possible shifts in relative abundance and composition of fishes warrants attention, and detailed examination of long-term datasets and continued monitoring of coastal fishes in the Gulf of Maine are necessary for elucidating status and trends.

Recent studies offered an opportunity to discuss fish community attributes observed in other Gulf of Maine nearshore systems. Chase et al. (2002) found 43 species, counting otter trawl (35 species) and seine (23 species) samples, in Salem Sound, Massachusetts. Discrete habitats were surveyed in Salem that were not investigated in Gloucester (i.e., eelgrass and tidal riverine habitats). Thirty-three species were found in Plum Island Sound, Massachusetts (Buchsbaum et al. 2003). Plum Island Sound contains extensive salt marsh habitats, and fishes were sampled using a beach seine and otter trawl. Kennebec and Wells Harbor, Maine, studies collected 27 and 24 fish species, respectively (Lazzari et al. 1999; Ayvazian et al. 1992). The Kennebec study used a fyke net to sample salt pond habitat and a beach seine to sample sandy beach habitat. Beach seine and otter trawls were used to collect fishes in intertidal and subtidal habitats (e.g., salt marsh, mudflat, and sandy beach) in Wells Harbor.

Twenty-nine fishes were collected in Gloucester Harbor, sharing species with the other boreal embayments of the Gulf of Maine (Ayvazian et al. 1992; Lazzari et al. 1999; Chase et al. 2002; Buchsbaum et al. 2003), a boreal-temperate mixed estuary of Cape Cod (Heck et al. 1989), and southern New England systems, such as Buzzards Bay (Wyda et al. 2002) and Narragansett Bay (Oviatt and Nixon 1973; Meng and Powell 1999). Similar species observed in southern New England waters and Gloucester Harbor were fishes with broad geographic range that overlap temperate and boreal environments, such as Atlantic silverside, cunner, mummichog, northern pipefish, red hake, threespine stickleback, and winter flounder, and fishes (e.g., sculpin species and lumpfish) that range from the northern portion of the Virginian zoogeographic province (i.e., New Jersey) northward through the Gulf of Maine (Bigelow and Schroeder 1953; Murdy et al. 1997).

Taxa were more similar among Gulf of Maine embayments that contained similar habitat features. Mummichog, Atlantic silverside, and stickleback species were dominant from samples in or near salt marsh habitat (Ayvazian et al. 1992; Lazzari et al. 1999; Buchsbaum et al. 2003). Winter flounder, skates, and Atlantic cod were the three most abundant species in Salem Sound (Chase et al. 2002) and Gloucester Harbor. Trawl stations sampled within Salem Sound and Gloucester Harbor were characterized by an unconsolidated soft sediment benthic environment, and the shoreline includes highly developed coast, sandy beaches, and exposed, rocky coast. Gloucester Harbor and Salem Sound are marine systems with areas of deep water and relatively little freshwater input; while systems with salt marsh habitat are generally located in regions with shallow water and comparably more freshwater flow.

This does not suggest that the urban qualities of Salem Sound and Gloucester Harbor are more or less productive than salt marsh systems, but does suggest that habitat features and functions in these areas are substantially different and support different species assemblages than the identified Gulf of Maine environments (Ayvazian et al. 1992; Lazzari et al. 1999; Buchsbaum et al. 2003). Species richness should be cautiously evaluated between studies because of the confounding factors, including methodology (e.g., sample periods, gear efficiency, and catch stability) and habitat type, extent, and condition, which influence fish species presence. The Gulf of Maine studies, in combination, elucidated the regional diversity of fishes inhabiting nearshore environments.

Nursery Habitat

A relatively diverse assemblage of early life stages of fishes were collected during this study and supported Jerome et al. (1969) observations of juvenile fish presence. Environmental requirements of early juvenile phases of fish and the relative importance of nearshore and offshore habitat conditions to early ontogenetic development is an important aspect of Gulf of Maine fish ecology. Processes that mediate survivorship and growth are especially important to fishes during their first year (Able and Fahay 1998). The understanding of environmental conditions necessary before and after settlement to the seafloor is well developed for tropical and temperate fishes (reviewed by Able and Fahay 1998), and the value of coastal waters to juvenile development is generally accepted (Hoss and Thayer 1993). This concept is not thoroughly described for Gulf of Maine waters.

Gloucester Harbor has experienced extensive urbanization and shoreline development along the inner harbor and development within the watershed during the past three centuries. Harbor waters were traditionally used for waste disposal (industrial and sewage), areas of the inner harbor contain contaminated seafloor sediments, navigation channels support active maritime industries, and contemporary inputs (e.g., urban and residential run-off) influence environmental quality. Despite the magnitude and extent of change to the natural environment, Gloucester Harbor contains nursery habitat. The persistence of important nursery habitats supported findings from other urban harbors, including Salem Sound (Chase et al. 2002), New Bedford Harbor (Wilbur et al. 1999; Geoghegan and Wilbur 2003), Providence River (Meng et al. 2002), and New York Harbor (Able et al. 1998 and 1999). The presence of resident species, including commercially exploited winter flounder and windowpane and non-target species (e.g., cunner, lumpfish, and rock gunnel), and the seasonal recruitment of marine YOY fishes (e.g., Atlantic cod, pollock, red hake and shorthorn sculpin) demonstrated the use of Gloucester Harbor as nursery habitat.

Habitat Relationships of Atlantic Cod, Winter Flounder, and Skate Species

Coastal waters, containing eelgrass beds and rocky bottom, and offshore shoal areas (e.g., northeast peak of Georges Bank) are important to Atlantic cod during their first year (Bigelow and Schroeder 1953; Fahay et al. 1999; Collette and Klein-MacPhee 2002). However, habitat requirements for recently settled cod are relatively unknown (Fahay et al. 1999). Howe et al. (2000b) described the importance of Massachusetts Bay coastal waters to YOY and age 1 cod, but the study did not include sampling within nearshore embayments and harbors. All Atlantic cod collected in this study were YOY, and many were newly settled juveniles (i.e., ~25-50 mm TL). Early life history stages tend not to migrate far from spawning locations (Fahay et al. 1999), suggesting Gloucester was in close proximity to spawning areas of the western Gulf of Maine. This study supported observations of high densities of juvenile cod inhabiting Massachusetts Bay and off Cape Ann (Fahay et al. 1999; Howe et al. 2000b). The modal progression of monthly length frequency from March to May 1999 provided evidence of growth and indicated the importance of harbor waters to early ontogeny. An interesting observation was the co-occurrence of YOY pollock with samples containing cod in April and May 1999.

Atlantic cod were collected within a range of unconsolidated soft mud to sand sediments (NAI 1999a; Valente et al. 1999; USGS 2000; SAIC 2001) and water temperature from 2.9°C (mid-March) to 12.5°C (early October 1998). The largest catches occurred from 4.6°C to 9.3°C (May 1999). The observation of YOY cod in October 1998 and spring 1999 indicated an extended spawning period through the summer or two distinct spawning episodes during the study, and supported and improved the Howe et al. (2000b) description of the value of shallow Gulf of Maine waters, including harbors, to juvenile cod.

Coastal waters are used by all life stages of winter flounder and are particularly valuable to spawning and early life history development (see review by Periera et al. 1998). Winter flounder collected were predominately YOY and age 1. Winter flounder were found all year (except February) at stations with unconsolidated mud and sand. Water temperatures ranged from 2.8°C (March 1999) to 16.5°C (early-September 1998), with peak abundance in late-October (10.5°C) to November (no temperature recorded) 1998 and April (4.7°C) to early-May (8.5°C) 1999. The highest catches were composed of young fish. The presence of YOY winter flounder and the non-dispersive behavior of eggs and larvae (Pereira et al. 1998) indicated that Gloucester Harbor was in the vicinity of spawning grounds and provided suitable nursery habitat. Larger winter flounder (>1 year) were seen in June-August 1998 and May 1999. Winter flounder remain common residents of nearshore waters despite diminished population levels (NMFS 1998).

Skates dominated the biomass of bottom-dwelling fishes and were the largest fish collected (i.e., >200 mm TL) throughout the study. Skates were observed at temperatures ranging from 4.6°C (26 May 1999) to 17.8°C (2 September 1998) and at stations with a range of unconsolidated soft mud and sand. Skate abundance (number and biomass) was relatively consistent from June to October 1998 and May 1999, with peak abundance in late-June 1998 (11.3°C) and mid-May 1999 (9.3°C). Skates apparently migrated offshore during winter. The abundance, size, and feeding habitats of skates (Packer et al. 2000a) suggested the skate complex could influence overall composition of the demersal fish and benthic community. Skates are carnivorous and feed on a range of benthic creatures, including fishes (review by Packer et al. 2000a). Direct predation or resource competition (e.g., competition for prey and habitat) may influence the composition and relative abundance of other demersal fishes. Effects of the proliferation of skate populations to other demersal fishes are unknown. Research is needed to determine the impact of skates to the seafloor community (including demersal fishes), predator-prey dynamics, niche overlap, and resource partitioning in coastal embayments.

Summary

Gloucester Harbor supported a relatively diverse fish assemblage, including economically and ecologically valuable species, and the occurrence and abundance of early life history stages of fishes indicated the presence of nursery habitat. The difference in species richness, species presence and relative abundance of common species between recent (Chase et al. 2002; Carey and Haley 2002; Buchsbaum et al. 2003) and historic studies (e.g., Jerome et al. 1969) suggested a shift in the demersal fish community of Massachusetts waters during the past several decades. This study cannot determine the cause of the shift. Long-term, systematic surveys and directed monitoring efforts are required to understand temporal and spatial trends of fish population or community fluctuation and results of human-induced perturbation to fishes and environmental functions. Offshore populations of commercially and recreationally important fish and crab species are evaluated by long-term stock assessments (NMFS 1998; Howe et al. 2000a), but human influences in these survey areas are mainly attributed to harvest (e.g., direct removal of species or physical habitat impact). Nearshore systems, including Gloucester Harbor, are influenced by many sources of natural and anthropogenic stress that potentially affect fish communities. It is unknown, given two targeted, short-term studies of fishes in Gloucester Harbor during the past 30 years, if or how environmental quality influences the productivity of fishes in Gloucester Harbor.

This study is the first characterization of the Gloucester Harbor fish community in more than 30 years; identifies seasonal and spatial features of relative abundance, composition, species richness, and life history characteristics of fishes for 1998-1999; indicates the importance of urban harbors to early life history stages of fishes; and improves the understanding of the nearshore fish community in Massachusetts waters. This study provides a basis for future research and monitoring questions regarding conditions that attract juvenile fishes to Gloucester Harbor; variation in environmental conditions among Massachusetts harbors, embayments, and offshore waters; and causal links between environmental quality and the growth and survivorship of fishes.

Acknowledgments

This study was a component of the Massachusetts Dredged Material Management Plan, supported by the Massachusetts Seaport Bond and the CZM Grant. Field work was completed by Normandeau Associates Incorporated (Paul Geoghegan, project manager), CZM, and DMF staff. DMF (Leigh Bridges and Vin Malkoski) and CZM (Deerin Babb-Brott, Anne Donovan, and Christian Krahforst) contributed to the study and reviewed early drafts of the manuscript. Robert Buchsbaum (Massachusetts Audubon Society), Brad Chase (DMF), and Michele Dionne (Wells National Estuarine Research Reserve) provided reviews that greatly improved the manuscript.

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APPENDIX 4.1 Total fish CPUE (number/400m) for otter trawl stations combined (72 trawls) in Gloucester Harbor.

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Skate spp.	10.1	38.3	12.2	10.8	17.8	21.2	28.4	12.1	27.5	29.8	6.0	1.0				4.1	54.0	17.0	290.1
Winter flounder	19.1	20.8	12.3	6.7	3.6	8.8	9.0	14.2	5.0	33.1	39.0	9.3	10.0		8.0	43.7	31.0	8.0	281.6
Atlantic cod		1.0				3.0			17.0	5.0	1.0				18.0	29.1	157.0	31.4	262.3
Red hake	2.0	4.0	4.7	3.8	1.0	1.0	2.0	2.0	2.0	4.0	8.0					2.0	3.0	2.0	41.4
Rock gunnel		1.0	0.9	0.9			1.0	4.2	1.0	2.1	5.0	1.1		2.0	7.0	1.0	4.0	8.0	39.1
Shorthorn sculpin	1.0	2.0							1.0		1.0				5.0	14.0	9.0	5.1	38.2
Pollock																21.1	7.0	8.0	36.1
Windowpane	1.0	3.2	6.7	2.0	1.9	1.9	2.2			1.0	2.0	1.1			1.0		6.0	2.9	32.9
Cunner				1.0			2.0	2.0	3.0	7.1	5.0			1.1	2.0	1.0	5.0	1.0	30.1
Grubby	2.1			1.9	1.8		1.1	4.2		5.1		5.3	3.0			1.0			25.4
Lumpfish							2.0	1.1		5.1	3.0	4.2							15.3
Rainbow smelt			0.9							1.0	4.0	4.3				4.0			14.3
Seasnail spp.						1.0										9.1	3.0	1.0	14.0
Longhorn sculpin							3.0	1.0	1.0		4.0	2.0					2.0		13.0
Northern pipefish							1.0		1.0	2.0	4.0					1.0			9.0
Sea raven		1.0							1.0								2.0	3.0	6.9
Radiated shanny		1.0														4.0			5.0
Ocean pout																2.9		1.0	3.9
Blueback herring					2.6														2.6
Butterfish							2.2												2.2
Atlantic silverside											1.0						1.0		2.0
White hake	1.0															1.0			2.0
Total	36.2	72.2	37.7	27.0	28.6	36.8	53.8	40.7	59.4	95.2	83.0	28.3	13.0	3.1	41.0	139.1	284.0	88.3	1167.3

APPENDIX 4.2a Total fish CPUE (number/400m) for Southeast Harbor (SEH) trawl sampling in Gloucester Harbor.

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Winter flounder	2.1	5.9	4.9	0.9	1.7	2.9	6.0	5.0	4.0	5.0	2.0					8.0	4.0	7.0	59.4
Skate spp.	2.1	9.8	4.9		0.9	5.9	4.0	3.0	6.0	9.0	1.0						1.0	9.0	56.4
Atlantic cod																15.0		25.0	40.0
Rock gunnel		1.0		0.9			1.0		1.0		5.0			1.0	4.0		4.0	8.0	25.9
Pollock																17.0		8.0	25.0
Shorthorn sculpin									1.0							6.0	2.0	4.0	13.0
Red hake	1.0	2.0	1.0			1.0	1.0			1.0							1.0	2.0	9.9
Cunner									1.0		1.0				2.0	1.0			5.0
Grubby	2.1			1.9															3.9
Longhorn sculpin							2.0	1.0											3.0
Radiated shanny																3.0			3.0
Blueback herring					2.6														2.6
Windowpane	1.0					1.0													2.0
Sea raven		1.0																1.0	2.0
Lumpfish												1.0							1.0
Northern pipefish											1.0								1.0
Ocean pout																		1.0	1.0
Seasnail spp.																1.0			1.0
White Hake																1.0			1.0
Total	8.2	19.5	10.7	6.5	5.2	10.7	14.0	10.0	14.0	15.0	10.0	1.0	0.0	1.0	6.0	55.0	12.0	65.0	263.9

APPENDIX 4.2b Total fish CPUE (number/400m) for Outer Harbor (OH) trawl sampling in Gloucester Harbor.

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Winter flounder	1.0	3.2	3.8	0.9	1.0	4.0	1.0	4.0		16.0		3.0				16.6	2.0		56.5
Atlantic cod						2.0			16.0	5.0					1.0	2.9	1.0	2.9	30.9
Skate spp.	1.0		1.0			1.0	1.0	4.0	1.0	6.0		1.0							16.0
Cunner							1.0	1.0	1.0	1.0	3.0						5.0	1.0	13.0
Shorthorn sculpin		1.1													2.0	2.0	2.0		7.0
Longhorn sculpin									1.0			2.0					2.0		5.0
Windowpane		1.1	1.9							1.0									4.0
Red hake			1.0							1.0	1.0						1.0		4.0
Grubby												1.0	2.0						3.0
Lumpfish							1.0			2.0									3.0
Seasnail spp.																	3.0		3.0
Sea raven									1.0									2.0	3.0
Ocean pout																2.9			2.9
Northern pipefish										2.0									2.0
Pollock																	2.0		2.0
Rock gunnel								1.0							1.0				2.0
Rainbow smelt																1.0			1.0
Total	2.0	5.4	7.6	0.9	1.0	7.0	4.0	10.0	20.0	34.0	4.0	7.0	2.0	0.0	4.0	25.4	18.0	5.9	158.1

APPENDIX 4.2c Total fish CPUE (number/400m) for Western Harbor (WH) trawl sampling in Gloucester Harbor.

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Atlantic cod		1.0				1.0			1.0						15.0	4.0	151.0		172.9
Skate spp.	7.0	8.6	6.4	9.8	8.9	13.3	18.0	3.0	20.5	10.7	5.0					2.0	39.0	6.8	159.0
Winter flounder	16.0	8.6	3.6	4.9	0.9	1.9	2.0	1.0	1.0	4.9	3.0	2.0	5.0			14.0	11.0	1.0	80.7
Windowpane			2.7	2.0	0.9	1.0					1.0				1.0		5.0	2.9	16.4
Red hake		1.0	2.7	1.0			1.0	1.0	1.0	1.0	4.0					2.0	1.0		15.6
Shorthorn sculpin		1.0													1.0	3.0	2.0		7.0
Pollock																1.0	5.0		6.0
Cunner							1.0	1.0		2.0	1.0								5.0
Grubby					1.8			1.0		1.0			1.0						4.8
Northern pipefish							1.0		1.0		2.0								4.0
Lumpfish							1.0				1.0	1.0							3.0
Seasnail spp.																3.0			3.0
Rainbow smelt			0.9													2.0			2.9
Rock gunnel			0.9												2.0				2.9
Atlantic silverside											1.0						1.0		2.0
Longhorn sculpin							1.0				1.0								2.0
White Hake	1.0																		1.0
Radiated shanny		1.0																	1.0
Total	24.0	21.0	17.3	17.6	12.4	18.1	25.0	7.0	24.4	19.5	19.0	3.0	6.0	0.0	19.0	31.0	215.0	11.7	490.9

APPENDIX 4.2d Total fish CPUE (number/400m) for Inner Harbor (IH) trawl sampling in Gloucester Harbor.

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Winter flounder		3.2						4.2		7.2	34.0	4.3	5.0		8.0	5.1	14.0		85.0
Skate spp.		20.0		1.0	8.0	1.0	5.4	2.1		4.1						2.1	14.0	1.1	58.8
Atlantic cod											1.0				2.0	7.2	5.0	3.4	18.6
Grubby							1.1	3.2		4.1		4.3				1.0			13.7
Shorthorn sculpin	1.0										1.0				2.0	3.1	3.0	1.1	11.2
Windowpane		2.1	2.1		1.0		2.2				1.0	1.1					1.0		10.5
Rainbow smelt										1.0	4.0	4.3				1.0			10.4
Rock gunnel								3.2		2.1		1.1		1.1		1.0			8.4
Lumpfish								1.1		3.1	2.0	2.2							8.3
Cunner				1.0					1.0	4.1				1.1					7.2
Red hake	1.0	1.1			1.0					1.0	3.0								7.1
Pollock																3.1			3.1
Longhorn sculpin											3.0								3.0
Butterfish							2.2												2.2
Seasnail spp.																2.1			2.1
Northern pipefish											1.0					1.0			2.0
Sea raven																	2.0		2.0
Radiated shanny																1.0			1.0
Total	2.0	26.3	2.1	2.0	10.0	1.0	10.8	13.7	1.0	26.7	50.0	17.3	5.0	2.1	12.0	27.7	39.0	5.7	254.4

APPENDIX 4.3 Sample period fish catch by number in Gloucester Harbor seine stations; all stations combined (71 hauls).

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Atlantic silverside					2.0	5.0	81.0	81.0	301.0			1.0		1.0	1.0	4.0		2.0	479.0
Lumpfish		1.0				1.0	37.0												39.0
Blueback herring		4.0	21.0																25.0
Atlantic menhaden							1.0		9.0	2.0									12.0
Grubby	9.0	1.0								1.0									11.0
Winter flounder		1.0					5.0	1.0	1.0	1.0		1.0					1.0		11.0
Northern pipefish		1.0	1.0					1.0	1.0	4.0									8.0
Mummichog					1.0				3.0		3.0								7.0
Red Hake	2.0	1.0	1.0				2.0		1.0										7.0
Rainbow smelt								2.0	3.0										5.0
Windowpane	1.0	2.0						1.0											4.0
Sand lance									2.0										2.0
Bay anchovy			1.0			1.0													2.0
Cunner	2.0																		2.0
3-spine stickleback	1.0																	1.0	2.0
Bluefish								1.0											1.0
Northern puffer							1.0												1.0
Pollock																	1.0		1.0
Rock gunnel	1.0																		1.0
Shorthorn sculpin																	1.0		1.0
Total	16.0	11.0	24.0	0.0	3.0	7.0	127.0	87.0	321.0	8.0	3.0	2.0	0.0	1.0	1.0	4.0	3.0	3.0	621.0

APPENDIX 4.4a Total fish catch (#/haul) for Pavilion Beach (PB) in Gloucester Harbor (17 hauls; no sample on 11 November 1998).

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Atlantic silverside							52.0		22.0			1.0				4.0		1.0	80.0
Windowpane	1.0	2.0						1.0											4.0
Mummichog									3.0										3.0
Red hake	2.0								1.0										3.0
Northern Pipefish								1.0	1.0										2.0
Winter flounder		1.0										1.0							2.0
Rainbow smelt									1.0										1.0
3-spine stickleback	1.0																		1.0
Total	4.0	3.0					52.0	2.0	28.0			2.0				4.0		1.0	96.0

APPENDIX 4.4b Total fish catch (#/haul) for Tenpound Island (TI) in Gloucester Harbor (18 hauls).

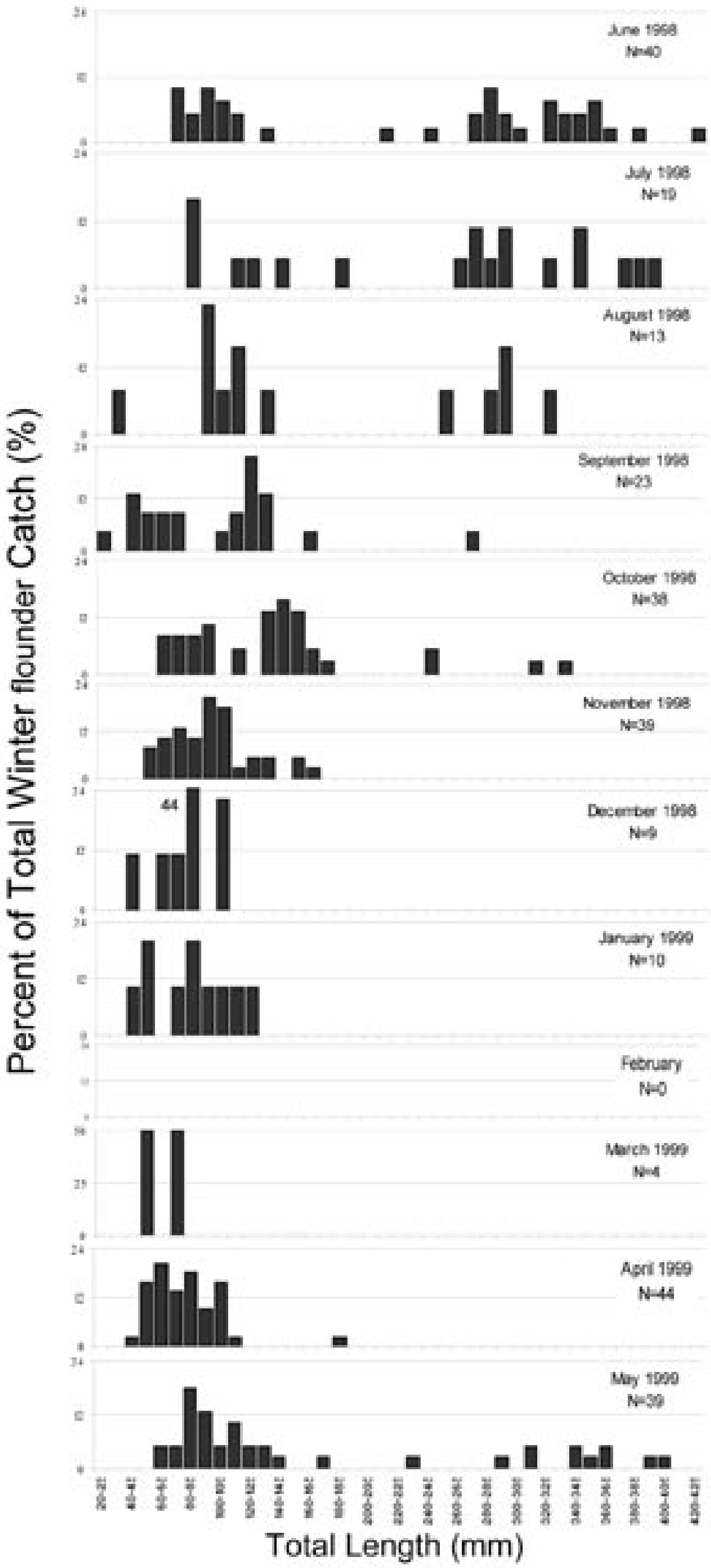
Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Blueback herring		4.0																	4.0
Atlantic silverside							3.0												3.0
Cunner	2.0																		2.0
Grubby	1.0	1.0																	2.0
Northern pipefish										2.0									2.0
Atlantic menhaden							1.0												1.0
Red hake		1.0																	1.0
Rock gunnel	1.0																		1.0
Shorthorn sculpin																	1.0		1.0
Total	4.0	6.0					4.0			2.0							1.0		17.0

APPENDIX 4.4c Total fish catch (#/haul) for Half Moon Beach (HM) in Gloucester Harbor (18 hauls).

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Atlantic silverside						5.0	25.0	81.0	276.0										387.0
Lumpfish		1.0				1.0	37.0												39.0
Blueback herring			21.0																21.0
Atlantic menhaden									9.0										9.0
Winter flounder							5.0	1.0	1.0								1.0		8.0
Grubby	4.0									1.0									5.0
Mummichog					1.0						3.0								4.0
Rainbow smelt								2.0	2.0										4.0
Red hake			1.0				2.0												3.0
Sand lance									2.0										2.0
Bay anchovy			1.0			1.0													2.0
Northern pipefish		1.0	1.0																2.0
Bluefish								1.0											1.0
Pollock																	1.0		1.0
3-spine stickleback																		1.0	1.0
Total	**4.0**	**2.0**	**24.0**		**1.0**	**7.0**	**69.0**	**85.0**	**290.0**	**1.0**	**3.0**						**2.0**	**1.0**	**489.0**

APPENDIX 4.4d Total fish catch (#/haul) for Niles Beach (NB) in Gloucester Harbor (18 hauls).

Species	6/12 1998	6/25 1998	7/9 1998	7/22 1998	8/6 1998	8/19 1998	9/2 1998	9/18 1998	10/8 1998	10/23 1998	9/11 1998	9/12 1998	1/25 1999	2/18 1999	3/18 1999	4/22 1999	5/12 1999	5/26 1999	Total
Atlantic silverside					2.0		1.0		3.0					1.0	1.0			1.0	9.0
Grubby	4.0																		4.0
Atlantic menhaden										2.0									2.0
Northern pipefish										2.0									2.0
Northern puffer							1.0												1.0
Winter flounder										1.0									1.0
Total	**4.0**				**2.0**		**2.0**		**3.0**	**5.0**				**1.0**	**1.0**			**1.0**	**19.0**



APPENDIX 4.5 Winter flounder length frequency in Gloucester Harbor, June 1998 to May 1999; trawl samples. N=total number of winter flounder collected per month.